III.A.5 Metal Interconnect for Solid Oxide Fuel Cell Power Systems

Objectives

- Select a surface treatment process for commercial ferritic stainless steel to reduce oxide scale growth rate.
- Optimize treatment process condition to provide a stable, conductive scale.
- Measure the scale properties in SOFC relevant conditions.
- Evaluate treated metal interconnects under SOFC stack conditions.

Approach

- Select a heat treatment process to achieve a thin, dense scale of a conductive oxide composition.
- Measure scale conductivity in air at target operating temperature.
- Measure air-side scale conductivity when the opposite side is exposed to fuel conditions (dual atmosphere test condition).
- Evaluate scale morphology under fuel cell operating conditions.
- Evaluate the effect of surface treatment on chromium volatility.
- Measure interconnect repeat unit resistance under stack operating conditions.

Accomplishments

- The surface treatment was found to reduce the scale growth rate as determined by thermogravimetry at 750°C. The treated metal coupons showed a parabolic rate constant of 5×10^{-9} $gm^2/cm^4/hr$ compared to 7×10^{-8} $gm^2/cm^4/hr$ of uncoated coupons. The low oxidation rate of treated interconnects will enable achieving the target fuel cell operating life of 40,000 hours.
- Scale resistance was 10 millohm-cm^2 in air at 750°C and less than one milliohm-cm^2 in humidified hydrogen.
- Scale morphology was characterized as a function of treatment process and test conditions relevant to fuel cell operation.
- Stable, low air-side resistance was demonstrated under dual atmosphere test conditions.
- Significant reduction in chromium evaporation was observed with treated metal coupons.
- No detectable reactivity of treated metal and potential cell joining perovskite compositions.

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Future Directions

- Verification of performance improvement in fuel cell stack tests.

Introduction

Interconnects perform essential functions in a fuel cell stack, namely, electrical connection between adjacent cells and separation of air and fuel. In many cases they also provide structural support for the stack. The use of commercial alloy offers the potential for low-cost interconnect components. This allows for achieving the DOE target of low cost, modular fuel cell stacks.

The SOFC interconnect must simultaneously satisfy several functional requirements. These functions require materials with high electronic conductivity for the series connection of individual single cells, gas impermeability to separate fuel and oxidant gases, and chemical stability and conductivity over a large oxygen concentration range in order to maintain integrity in both the fuel and air atmospheres. Thermal expansion match with the rest of the cell elements is desired. Metal interconnects are very desirable from the viewpoints of manufacturing cost in addition to other functional requirements, provided that the high conductivity can be maintained at the operating conditions. It also lends itself to ease of fabrication of gas channels and greater control over dimensions to help improve the conformity as well as uniform reactant distribution to ensure uniform current density, high fuel utilization and high fuel efficiency. The use of thin metallic sheets will also reduce overall weight in the fuel cell system. High thermal conductivity of metal interconnects will help distribute the heat generated during the operation of the cell, thereby reducing the cooling air requirement as well as eliminating thermal stress failure of ceramic components caused by sharp thermal gradients.

The principal requirements of metal interconnects can be summarized as follows: 1) thermal expansion match with other cell components, 2) oxidation resistance in air and fuel at the operating temperature, 3) conductive interface (scale) in air and fuel atmospheres, 4) prevention of reactivity with electrode materials to form insulating compounds, 5) low volatility of major or minor constituents that poison electrode activity, 6) compatibility with anode and cathode environments, 7) uniformity in contact with the cells, 8) thermal cycle capability, and 9) cost. The present work focuses on the development and evaluation of conductive oxide scale on commercial ferritic stainless alloys.

Approach

A commercial stainless steel alloy was selected. The surface oxide scale was modified using an appropriate coating and heat treatment process to provide a dense conductive oxide scale. A second treatment layer was applied to provide a low chromium activity in the surface. Process development to achieve both treatments in a single step was completed. The growth rate, resistivity, and morphology of the scale were determined as a function of time for the various surface treatment conditions. The evaluations were made both in single atmosphere (air or fuel) or dual atmosphere (air and fuel on the opposite sides) conditions. Comparison of chromium evaporation characteristics of treated and untreated metal coupons was made using alumina powder as the chromium getter.

Results

Thermogravimetry of a 400-series commercial stainless steel was performed. Both untreated and treated coupons were evaluated. Two types of treatments were done. The first one was to heat treat the coupon to grow a controlled, dense oxide scale layer (treatment 50C940). In a second variation, an additional treatment was done to provide a stable chromium oxide composition as the outer layer (treatment MI2). The comparison of the oxide scale growth, via weight gain, is shown in Figure 1. The pre-grown oxide layer was found to reduce the scale growth significantly while the second treatment provided an additional reduction in scale growth rate.

The resistances of the coupons were measured after they were surface treated. Two coupons were sandwiched using a conductive perovskite (e.g., Sr-doped lanthanum cobaltite) as the contact paste. The change in measured resistance values of the coupon couples at 750°C in air is shown in Figure 2. The coupons were subjected to several thermal cycles. Similar measurements were also made in humidified hydrogen using nickel paste as the contact layer,

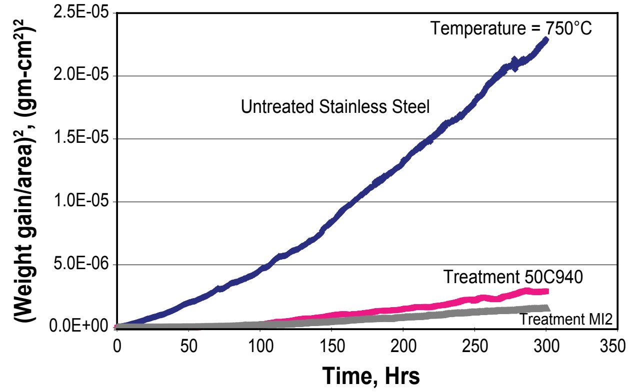

FIGURE 1. Thermogravimetry of Ferritic Stainless Steel Coupons

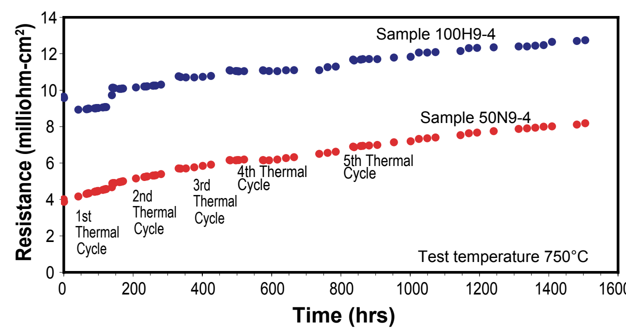

FIGURE 2. Resistance of Coupon Couples in Air at 750°C

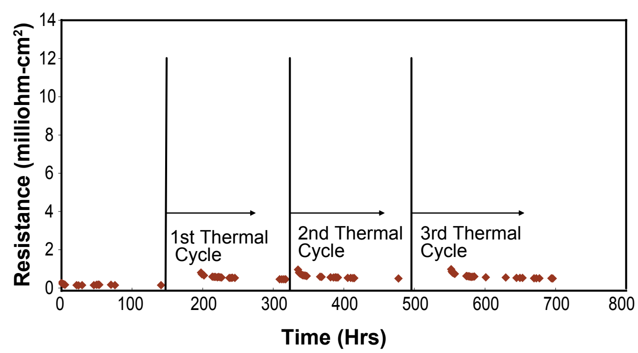

FIGURE 3. Resistance of Coupon Couples in Humidified Hydrogen at 750°C

shown in Figure 3. In both atmospheres, the resistance values were below 10 milliohm-cm^2, meeting the target interconnect resistance.

Earlier work showed that the oxide scale on the air-side is disrupted when the opposite side is exposed to hydrogen at the target cell operating temperature. In order to evaluate the effect of dual atmosphere exposure, resistance of coupon couples were measured when one coupon is exposed to dual atmosphere. The test arrangement and the results of a test using the graded scale composition are shown in Figures 4a and

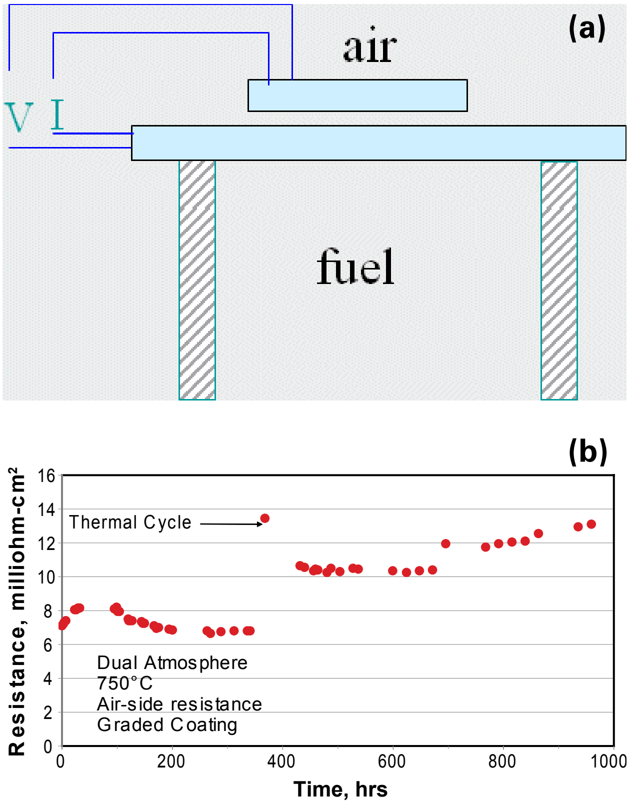

FIGURE 4. Test Configuration (a) and Resistance (b) of Coupon Couples in Dual Atmosphere at 750°C

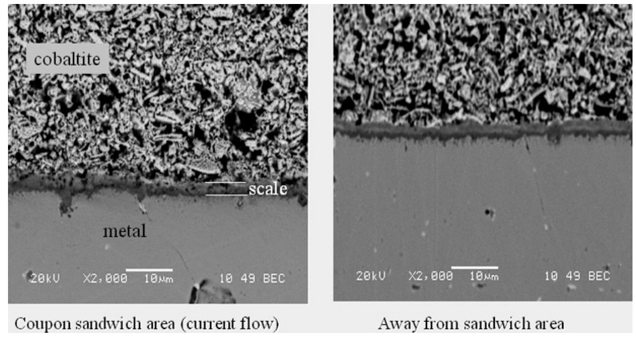

FIGURE 5. Scale Microstructure after the 1,000-Hour Test

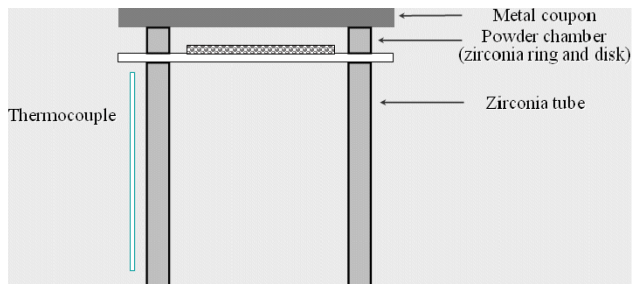

FIGURE 6. Test Configuration for Chromium Evaporation Assessment

4b, respectively. The low resistance measured under realistic exposure conditions is encouraging. The scale microstructure after the 1,000-hour test is shown in Figure 5. Both the sandwich area with the current flow in and away from the sandwich area show thin (~3 micron) oxide scale, thus confirming the effectiveness of the treatment under a dual atmosphere exposure.

Chromium evaporation characteristics of the untreated and treated metal coupons were evaluated using an alumina getter. A schematic of the test arrangement is shown in Figure 6. Various coupons were exposed to the getter material at 750°C for 300 hours. A significant reduction in chromium content was noted for the treated coupons as shown in Table 1.

Mixtures of treated and untreated stainless steel powder and perovskite powder were heat treated to evaluate the reactivity. The treated metal powder did not show any evidence of new phases based on x-ray diffraction analysis.

A resistance stack consisting of a series of interconnects with different treatments was tested to simulate the dual atmosphere stack conditions. Initial results showed low resistance for some segments. Additional tests are required to obtain statistical information on the performance variations.

TABLE 1. ICP Analysis of Al_2O_3 Powder (ppm by weight)

	Cr
Baseline powder	< 0.5
Powder exposed to untreated coupon	250
Powder exposed to treated coupon	140
Powder exposed to treated and LSCo thermal sprayed coupon	4.1

Conclusions

- Surface treatment to commercial ferritic stainless steel is shown to reduce the oxidation rate in air at SOFC operating temperatures.
- The resistance values of the stainless interconnect meet the target.
- The surface treatment provides improved stability to the scale under dual atmosphere exposure conditions.
- A significant reduction in chromium evaporation rate demonstrated.
- The treatment also suppresses reactivity of metal with cell joining perovskite materials.

FY 2006 Publications/Presentations

1. "Selection and Surface Treatment of Alloys in Solid Oxide Fuel Cell Systems," S. Elangovan, S. Balagopal, J. Hartvigsen, I. Bay, D. Larsen, M. Timper, and J. Pendleton, Journal of Materials Engineering and Performance, August 2006, in press.